# Swashzone Fluid Velocities

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## LONG-TERM GOALS

The long-term goal is to develop and verify models for fluid and sediment processes in the swash zone.

## OBJECTIVES

The overall objective of these projects is to improve models for fluid velocities in the swash zone. Although runup excursions and cross-shore swashzone velocities owing to random waves on a natural beach are predicted well by a model (Rbreak) based on the vertically-averaged nonlinear shallow water equations with quadratic bottom friction (*Kobayashi et al.* 1989, *Raubenheimer et al.* 1995, *Raubenheimer* 2002), it is not clear whether the alongshore velocities are predicted accurately. Furthermore, despite recent results that suggest alongshore sediment transport occurs primarily in the swash and outer surf zones (*Bodge and Dean* 1987, *Kamphuis* 1991, *Thornton and Abdelrahman* 1991), few studies have examined the importance of alongshore swashzone currents. The specific objectives of these projects are to:

- measure cross-shore and alongshore fluid velocities in the swash zone.
- use the observations to test and improve numerical model predictions of cross- and alongshore fluid velocities.

## APPROACH

Comparisons of field and laboratory observations with numerical model predictions are being used to investigate swashzone processes, including the fluid velocities that are important to sediment transport. Field observations of the cross-shore structure of cross-shore swashzone fluid velocities have been compared with Rbreak predictions (*Raubenheimer* 2002). Alongshore flows in the swashzone, which depend on the instantaneous location of the moving shoreline, previously have been simulated using the time-dependent, weakly two-dimensional, nonlinear shallow water equations (*Kobayashi & Karjadi* 1996, *Brocchini* 1997). Ongoing work will focus on testing these models with field observations. Waves and wave-driven circulation were measured with pressure gages and current meters deployed on a cross-shore transect extending across the surf and swash zones to the beach face. Drifters were used to estimate the locations, flow speeds, and offshore extents of rip currents.

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To account for the moving shoreline location, swashzone flows will be investigated using a time-dependent nonlinear shallow water equation model. Assuming small incident wave angles and gradual alongshore variations of the local bathymetry and waves, the two-dimensional nonlinear shallow water equations are:

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(hu)=0$$
$$\frac{\partial}{\partial t}(hu)+\frac{\partial}{\partial x}\left(hu^2\right)=-gh\frac{\partial \eta}{\partial x}-\frac{1}{2}f_c|u|u$$
$$\frac{\partial}{\partial t}(hv)+\frac{\partial}{\partial x}(huv)=-gh\frac{\partial \eta}{\partial y}-\frac{1}{2}f_c|u|v$$

where $x$ and $y$ are the cross- and alongshore distances, $t$ is time, $h$ is the instantaneous total water depth, $\eta$ is the instantaneous deviation from the still water depth, $u$ and $v$ are the instantaneous depth-averaged cross- and alongshore velocities, and $f_c$ is an empirical friction factor. Offshore boundary conditions will be provided from pressure and velocity observations in 2.5-m depth. Friction factors for alongshore flows will be determined by fitting the model predictions to the observations (e.g., *Raubenheimer et al.* 2004). The model will be used to investigate the relative importance of forcing by cross-shore gradients of the alongshore radiation stress $S_{xy}$ and the alongshore gradients of setup and mean water depth to the alongshore surf and swashzone flows.

**WORK COMPLETED**

A cross-shore transect of 8 collocated pressure gages and current meters was deployed across the inner surf and swash zones from Oct 25 until Nov 18 2003 (Figure 1). Four additional internally-recording pressure-current meter systems were deployed from Oct 26 until Nov 6 on cross-shore transects at several locations north and south of the main swash sensors to obtain information about alongshore gradients of swash flows. Nine internally-recording pressure-current meter systems were used to augment the main cross-shore transect (and to examine flow reversals, *e.g.*, Figure 2b) from Nov 10 until Nov 18. Vertical locations of swashzone velocimeters were adjusted frequently to maintain roughly constant elevations above the bed. Sand levels at the swash sensors were measured hourly during daylight. Foreshore sand level surveys from the bluffs to about 1 m water depth were conducted at low tide every two to three days. Preliminary processing of surf and swashzone measurements is nearly complete, and a database of wave heights, wave directions, wave-orbital velocities, and mean currents is being constructed. A wide range of wave conditions was observed, including offshore wave heights ranging from 40 to 130 cm, bulk incident wave directions from –5 to +7 deg relative to normal incidence, and alongshore surf- and swashzone flows from near zero to 75 cm/s and 40 cm/s, respectively.

On 2 days, Lagrangian drifters (Figure 2, and see *Schmidt et al.* 2003) repeatedly were deployed within a hundred meters of the cross-shore transect, providing flow measurements from the inner surf zone to a few hundred m offshore. Circulation patterns from the drifter trajectories will be used to estimate the locations, flow speeds, and offshore extents of rip currents, and will augment observations acquired with the in situ sensors

***Figure 1: Array of pressure gages and current meters deployed on tripods extending from seaward of the surf zone (background) across the inner surf and swash zones (foreground).***

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***Figure 2: Photo of deployment of 8 drifters south of the in situ instrument transect.***

## RESULTS

Model simulations (*Kobayashi & Karjadi* 1996, *Brocchini* 1997) and NCEX observations (Figure 3) suggest that alongshore swashzone flows can be strong, and that cross-shore gradients in surf and swashzone flows can be large. When incident wave angles were greater than a few degrees, mean alongshore flows were observed to be unidirectional, increasing from outside the breakers to the mid-surfzone, decreasing to the inner-surfzone, and then increasing again across the swashzone (*e.g.,* Figure 3a). When waves were near normally-incident, alongshore surf- and swashzone flows were sometimes observed to reverse direction with decreasing water depth (*e.g.*, outer- and mid surfzone flows are to the south in Figure 3b, whereas inner-surf and swashzone flows were to the north). It is hypothesized that the changing direction of the flows results from changes with decreasing water depth of the relative importance of forcing by obliquely-incident waves, by alongshore setup gradients, and by alongshore bathymetric inhomogeneities. Preliminary analysis suggests that tidally-driven flows also occasionally may be strong in the swash.

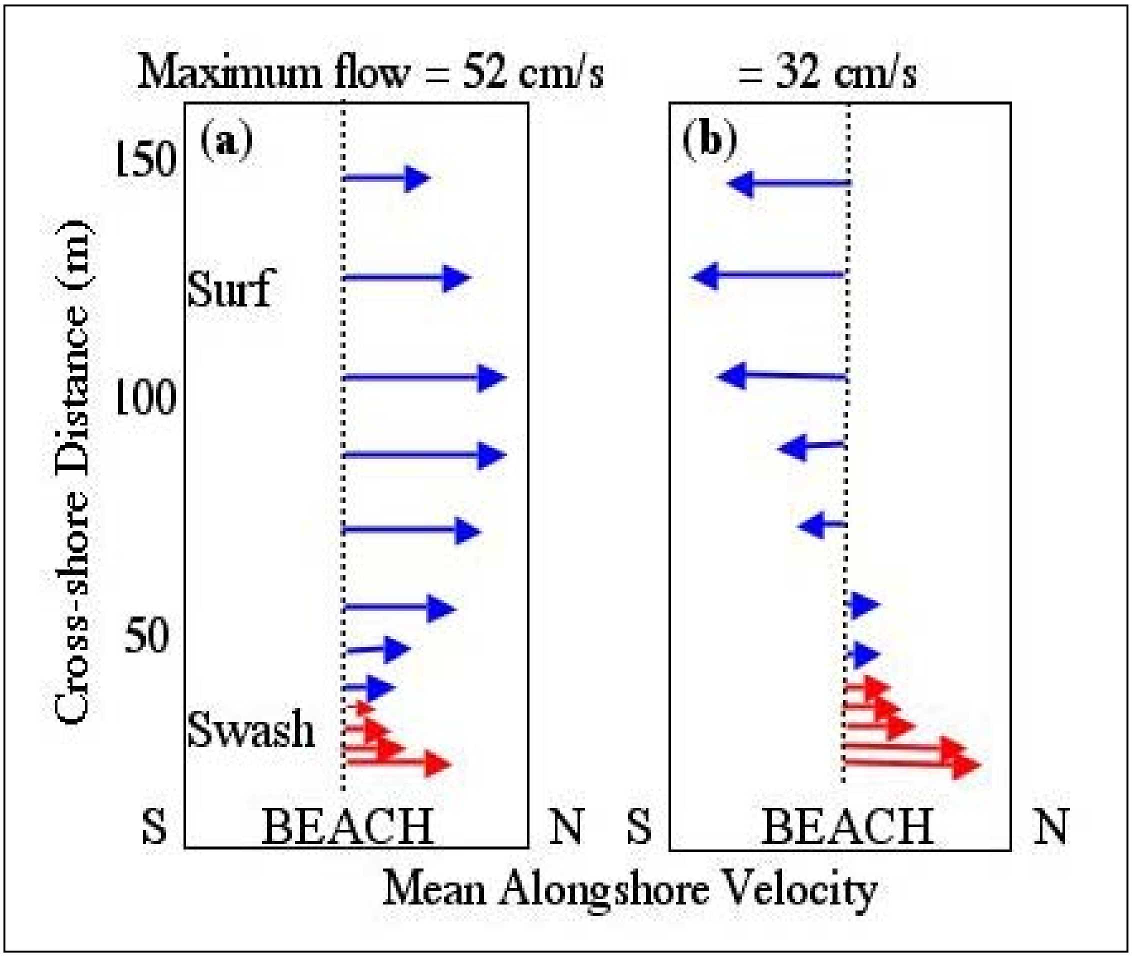


***Figure 3: Mean (1 hr) alongshore flows observed for 120-cm high waves (A) approaching the beach from 5 deg south of normal incidence on Nov 16 and (B) from near normal-incidence on Nov 17 along a cross-shore transect extending from the surf (blue arrows) to the swash (red arrows). Swashzone flows are averaged over times when the sensors were submerged. Maximum alongshore flows were 52 and 32 cm/s in (A) and (B), respectively.***
***[Flows are observed to increase from the outer to mid-surfzone, decrease to the inner-surfzone, and increase across the swashzone. Maximum swashzone flows are almost as strong as maximum surfzone flows. On Nov 17, the flows were to the south in the outer- and mid-surfzone, and were to the north in the inner-surf- and swashzones.]***

## IMPACT/APPLICATIONS

Validated models of wave runup velocities may provide spatially dense predictions of cross-shore and alongshore swashzone flows to drive sediment transport models and to estimate morphological change. It is expected that the observations and field-tested models discussed here also will be useful to extend surfzone models into the swash zone.

## RELATED PROJECTS

Observations from the *in situ* sensors in the SwashX experiment (fall 2000) have been used to evaluate drifter-based estimates of swash and surf zone velocities (Schmidt et al. 2003). The observations also are being used by Adrian Predrozo-Acuna (graduate student at Plymouth Univ.) to evaluate predictions of nonlinear shallow water and Boussinesq models. NCEX and SwashX observations are being used by Drs. Tim Maddux (Oregon State Univ., *Maddux et al.* 2002) and Tom Hsu (WHOI) to drive and evaluate models for swashzone sediment transport, and by Dr. Steve Lentz (WHOI) to investigate internal bores. NCEX measurements will be used by WHOI-MIT graduate student Alex Apotsos to evaluate models for wave-driven setup.

The NSF Career program has provided funds for undergraduate student fellows to conduct 6-month-long projects to investigate swash processes observed during SwashX, NCEX, and future experiments. Rachel Horwitz examined the importance of incident wave direction to the reversing flows observed during NCEX on Nov 17, Kristie Loncich is studying the relationship between convergences of the alongshore flows and development of a large accretionary sand wedge in early October 2003, and Catie Lichten is investigating the effect of gradual alongshore bathymetric inhomogeneities on wave transformation and setup predictions.

## REFERENCES


Bodge, K.R., and R.G. Dean, Short-term impoundment of longshore transport, *Proc. Coastal Sed. '87,* 468-483, 1987.

Brocchini, M., Eulerian and lagrangian aspects of the longshore drift in the surf and swash zones, *J. Geophys. Res.*, **102**, 23,155-23,168, 1997.

Kamphuis, J.W., Alongshore sediment transport rate, *J. Waterw. Port Coastal Ocean Eng.*, **117**, 624-640, 1991.

Kobayashi, N., G. S. DeSilva, and K. D. Watson, Wave transformation and swash oscillation on gentle and steep slopes, *J. Geophys. Res.*, **94**, 951-966, 1989.

Maddux, T.B., B. Raubenheimer, S. Elgar, Predictions of cross-shore sediment transport in the inner surf and swash zones, *EOS Trans*., **83**, 2002.

Raubenheimer, B., Observations and predictions of fluid velocities in the surf and swash zones, *J. Geophys. Res.*, **107**, 3190, doi:10.1029/2001JC001264, 2002.

Raubenheimer, B., R.T. Guza, S. Elgar, and N. Kobayashi, Swash on a gently sloping beach, *J. Geophys. Res.,* **100**, 8751-8760, 1995.

Raubenheimer, B., Steve Elgar, and R.T. Guza,  Observations of swashzone velocities: A note on friction coefficients, *J. Geophys. Res*., **109**, C01027, doi:10.1029/2003JC001877, 2004.

Schmidt, W.E., B.T. Woodward, K.S. Millikan, R.T. Guza, B. Raubenheimer, and S. Elgar, A GPS-tracked surfzone drifter, *J. Atmos. Ocean Tech.,* **20(7**), 1069-1075, 2003.

Thornton, E.B., and S. Abdelrahman, Sediment transport in the swash due to obliquely incident wind waves modulated by infragravity waves, *Proc. Coastal Sed. '91*, 100-113, 1991

**PUBLICATIONS**

REFEREED PAPERS:

Cowen, E.A., I.M. Sou, P.L.-F. Liu, and B. Raubenheimer, PIV measurements within a laboratory generated swash zone, *J. Eng. Mech*., **120(10)**, 1119-1129, 2003 [published, refereed].

Raubenheimer, B., Steve Elgar, and R.T. Guza, Observations of swashzone velocities: A note on friction coefficients, *J. Geophys. Res*., **109**, C01027, doi:10.1029/2003JC001877, 2004 [published, refereed].

CONFERENCE ABSTRACTS, INVITED TALKS, AND UNREFEREED PAPERS:

Raubenheimer, B., Alongshore variability of erosion, *Oceanus*, in press, 2004.

Raubenheimer, B. Surfzone morphology, presentation at WHOI Coastal Forum entitled “The Moving Shoreline: Coastal Change in Response to Rising Sea Level", Apr 2004.

Raubenheimer, B., Shoreline change: Days to years, presentation to WHOI Trustees, Sep 2004.

Raubenheimer, B., Modeling and measurement of swashzone fluid velocities, presentation at ICCE Swashzone Workshop, Sep 2004.